PowerOn AUSTRALIA

48 Volt Lithium Battery fault current test report

Product: POATLFeLi-48100F-E
Product Type: 48 Volt Lithium Battery
Test: Fault current
Release date: 12 October 2023

LFP Battery Assessment

Executive Summary

Power On works extensively in the mining industry supplying custom designed Power systems and UPS. Since we are exposed to changes in technology in power systems on a routine basis, periodic reviews of our knowledge base are carried out.

The most recent review pointed out that LFP batteries are becoming more and more common in industrial scenarios, driven by reduced footprint, increased environmental hardiness and greater cycling ability. It is noted that Lithium batteries have many different chemistries and presently, LFP or LiFePO4 construction is accepted as the industry standard.

However, the knowledge base for the behaviour of LFP batteries within the typical 'switch room' is practically non-existent. Significant research time and effort was spent attempting to locate performance characteristics – specifically safety related behaviours such as arc flash levels and fault current capabilities – without result.

Consequently, Power On chose to investigate actual electrical safety aspects of 48V LFP batteries as sold by POA for design knowledge reasons, and customer information reasons.
The decided scope of works for this information gathering exercise is as follows:

- Assess behaviour of provided LFP blocks in Short Circuit circumstances – BMS functional.
- Assess behaviour of provided LFP blocks in Short Circuit circumstances – BMS Non-functional.
- Assess what sort of Arc values are sustained during a potential Arc Fault condition.
- From this data, extrapolate 'Typical' real world values for per Block Fault current contribution, and compare with manufacturers published data (where available)
- Investigate the effects of additional resistance stages on fault currents, to gain a more factual grasp of fault current contributions in installed, rather than "on the bench".

As a result of this, we expect to walk away with a data set that predicts with some reliability, how the LFP battery blocks we supply, behave in electrical fault conditions, and what effects this will have on our customed systems. This data set can then be integrated into our design parameters to ensure system safety for Power On designs.

Safety Review

Before testing was undertaken, a safety review was conducted. A summary of this is,

- Maximum expected voltage during test = 54VDC.
- Manufacturer specifies Battery resistance is 9.73 milli Ohm.
- Using V=IR, calculated current maximum current flow is 5550 AMPS at the battery terminals.
- A typical short circuit duration, as limited by a circuit breaker, is 0.2 of a second.
- Using the DC Arc Flash by Corey Steven Weimann as a guide, the DC Arc Flash risk was deemed to be Category 0 (lowest). External checks with www.ea-guide.com/guides/dc-arc-flash-guide confirmed the value to also be Category 0.
- As a safety precaution Category 2 PPE was used during the testing.

Equipment Used:

- Eaton 48V 100Ah LFP Battery with BMS. SoC was 100% and SoH was 100%. During testing, the SoC did not drop below 98%.
- Hioki PW3198 Recording Power Analyser, with a 20kHZ per channel data recording rate.
- 3 Pole, 100-amp 15kA MCB with all 3 poles paralleled.
- 100Mv = 200 Amp current shunt of fixed resistance.
- Various Cables.
- Various handheld meters for polarity checks.
- Face Masks, Protective Eyewear, Leather Gloves, leather Apron, Personal PPE, Ear protection and safety Boots.
- CO2 Gas fire extinguisher.
- Steel Benches etc.
- 200-amp load bank (set to 77 amps load) to verify readings prior to any test.

Test Method

Circuit Resistance.

The resistance of the cables, shunt, and switch (100 amp, 3 pole CB) were measured. This was done by placing a 100-amp load through the circuit and measuring the volt drop across the circuit. The Shunt resistance with cables was measured at 0.000507 ohms and the circuit breaker was measured at 0.002 ohms.

Calculated Fault Current.

The test circuit added extra resistance to the internal battery resistance. The actual test circuit and battery resistance was determined to be .012273 ohms, giving a theoretical fault current of 4.4kA.

Measurements.

The current was measured using the Hioki meter. Two methods of calculating the current and a battery voltage measurement were recorded. The first method to measure the current using the Hioki DC Clamp set to fast response. The Second method was to use the volt drop across the shunt. The voltage measurement was directly across the battery terminals.

Test verifications.

Prior to short circuit testing, the Hioki was repeatedly tested using a 77-amp load (Load Bank) to confirm correct data. Sample tests proved to be accurate on the Hioki DC clamp, however, at a 77-amp load, the volt drop across the shunt was too low to be of any use with the Hioki recorded values.

During the actual testing, it become apparent that although the shunt showed similar results to the DC Clamp Meter, the values were very granular and did not show a smooth graph. This was deemed to be a result of the relatively low DC voltage across the shunt when compared to the actual intended use of the voltage input on the Hioki Meter (A 200-amp load on the shunt measures 0.1 v DC. The input designed to measure up to 600vDC with a 16 bit sensitivity). As a double check to ensure the DC Clamp was accurate the shunt was successful, however all results shown below are based on the DC Clamp Meter. The shunt remained in the circuit for the duration of the testing. One point to note, the DC clamp meter had a slight delay in the peak values when compared with the shunt values. This is assumed to be due to the extra processing of the clamp meter over the shunt voltage. Estimated delay is 0.0001 seconds. This recording delay had no effect on the results and little effect on the graphs.

Event Energy.

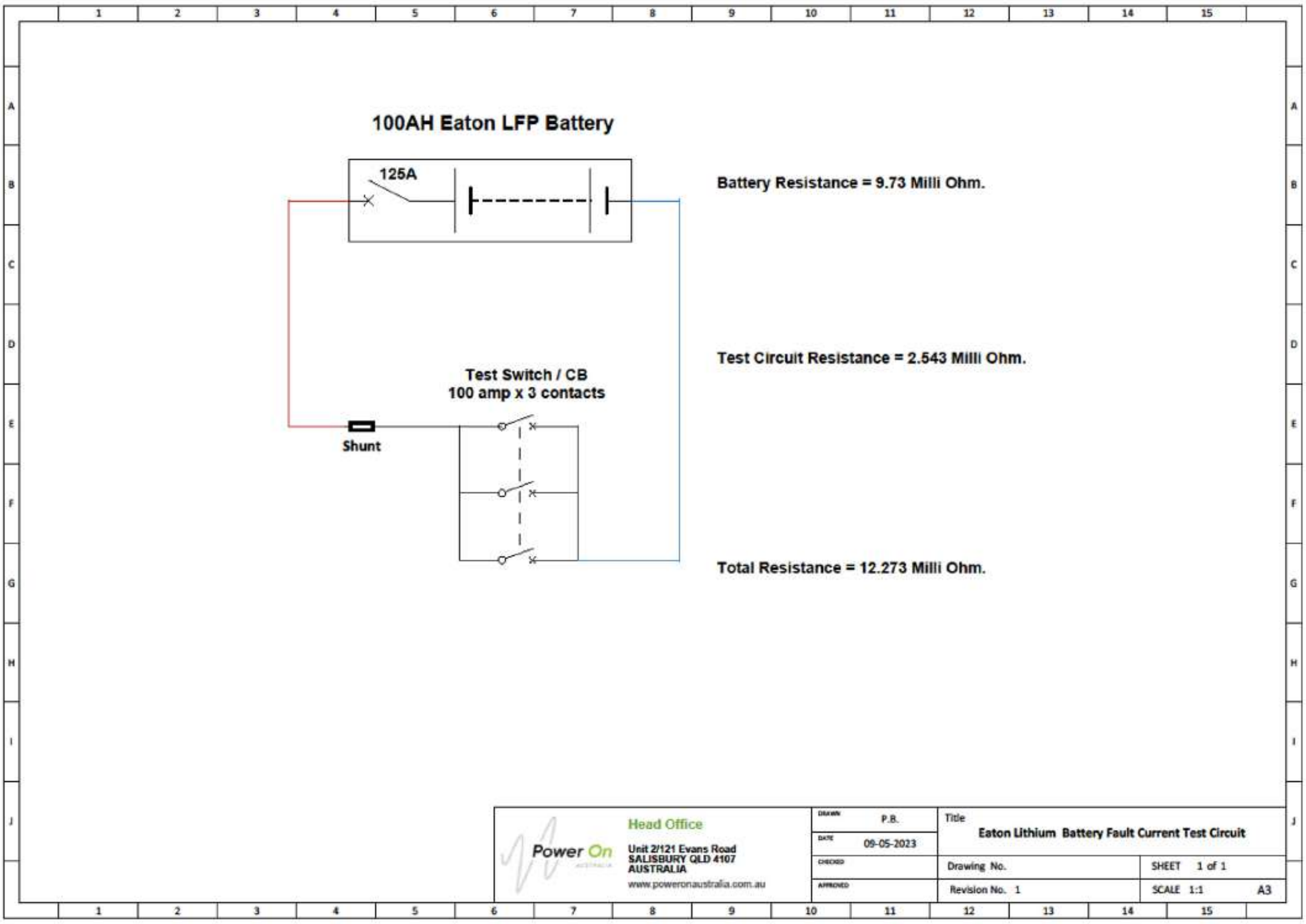
Where possible, the Total Event Energy has been calculated out in Joules.

An additional value of Arc Flash Incident Energy has been added. This value is based on the actual energy Joules using a Joules to calories conversion using a formula provided by Rio Tinto. The value is for open air or un-enclosed.

All values were well within Category 0 limitation of 1.2Cal/cm2.

As a reference for the value of a Joule, a teaspoon of water (5 grams) requires 838 Joules to go from 20 degrees Celsius to 60 degrees Celsius. The largest event recorded in our testing was 739 Joules.

Test Circuit



Test 1 Short Circuit. Fully functional battery with standard BMS control.

The +ve and -ve of the battery were short circuited via the above wiring details with a total circuit resistance of 0.012273 ohms.

- The duration of initial event was less than .001 seconds, in which time our analyser recorded 17 values.
- The peak current recorded as an ANALOG value was 438 amps.
- The total energy released as electrical energy during the short circuit event, between initiation and zero cut off was less than 1 Joule (watt seconds) (volts x amps x time, summed across the direction)

With an operational BMS, the energy discharged on a short circuit was minimal.

This test had a duration of less than 0.00085 of a second. (17 event lines of data on a 20Khz scan rate)

Event Joules = Less than 1.

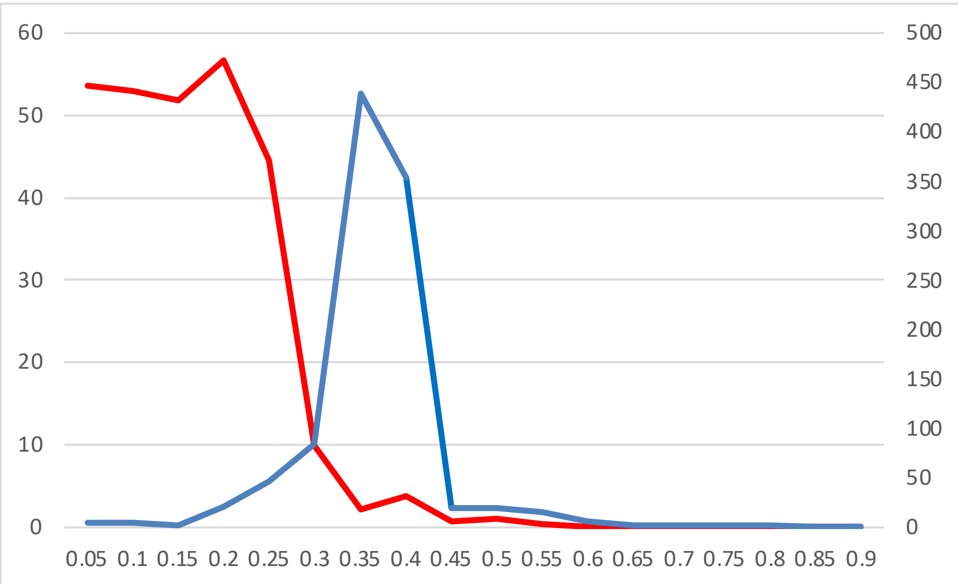
Arc Flash Incident Energy = 0.00001 Cal/cm2. Category 0.

Arc Flash Boundary = 1.3mm

Time in Milli Seconds

Red = Volts

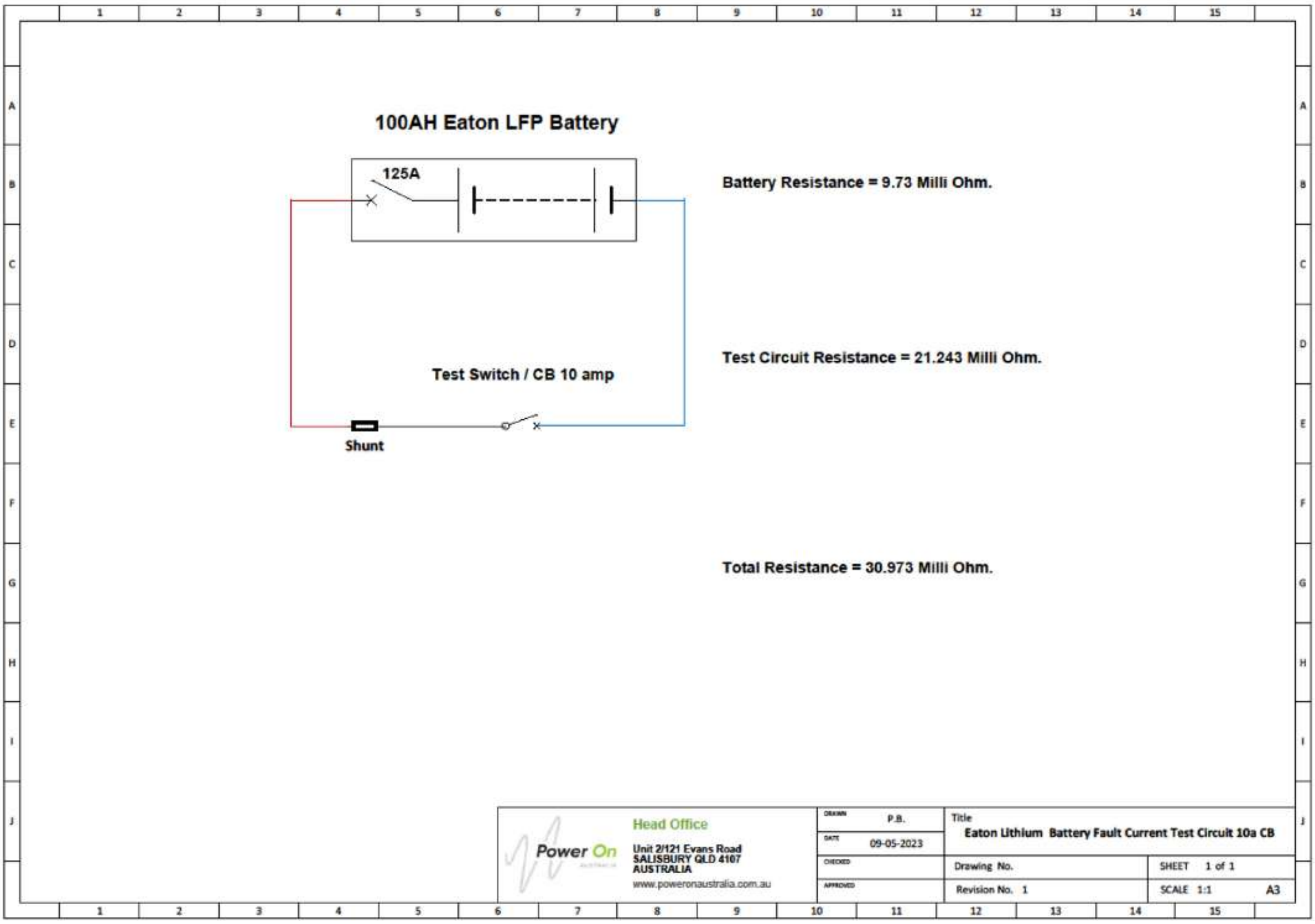
Blue = Amps.



This test was performed a total of 8 times. The duration and maximum current were similar in all tests with the highest current being 473 amps. All events were under 1 milli second in duration. The above graph is typical of the results of the 8 tests.

Test 2 Short Circuit. Fully functional battery with standard BMS control.

For this test only, the short circuit switch was replaced with a 10-amp ABBS201 C Curve circuit breaker. For this test, the internal resistance was calculated at 30.973 Milli Ohms for a maximum possible fault current of 1.75KA.



Test 2 Short Circuit. (Continued)

This test showed similar results to the previous short circuit test even with a much higher circuit resistance.

- The duration of initial event was less than .001 seconds.
- The peak current recorded value was 417 amps.
- The total energy released as electrical energy during the short circuit event, between initiation and zero cut off was less than 1 Joule (watt seconds) (volts x amps x time, summed across the direction)

With an operational BMS, the energy discharged on a short circuit was minimal.

Event Joules = Less than 1.

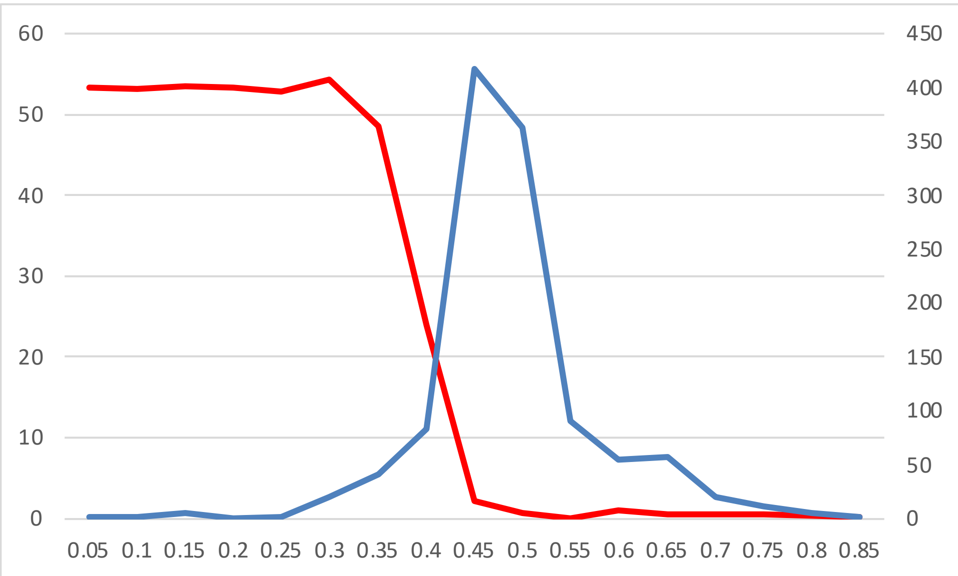
Arc Flash Incident Energy = 0.00001 Cal/cm2. Category 0.

Arc Flash Boundary = 1.3mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



The full short circuit capabilities of the 100 AH, 48v battery was directly across an off the shelf, 6KA rated, 10-amp C curve circuit breaker. Note: the 10-amp circuit breaker did not trip during this test. The BMS cut power before the circuit breaker could trip.

The exceptionally good results from the above tests would be the typically expected function when a short circuit is applied to the battery terminals of an Eaton Lithium Battery.

Test 1 Short Circuit. No BMS.

The testing below was done to enable us to better understand the fault currents that could occur in the unlikely but possible event of a “BMS Failure followed by a Short Circuit Event”.

The internal BMS was disconnected by moving the -ve wires internally, bypassing the BMS. This allows the full power of the batteries to be available via the internal 125-amp circuit breaker without BMS control.

A full short circuit test was performed.

The measured fault current peaked at 3861 amps with an event duration of approximately 4.2 milli seconds before the 125-amp battery circuit breaker tripped.

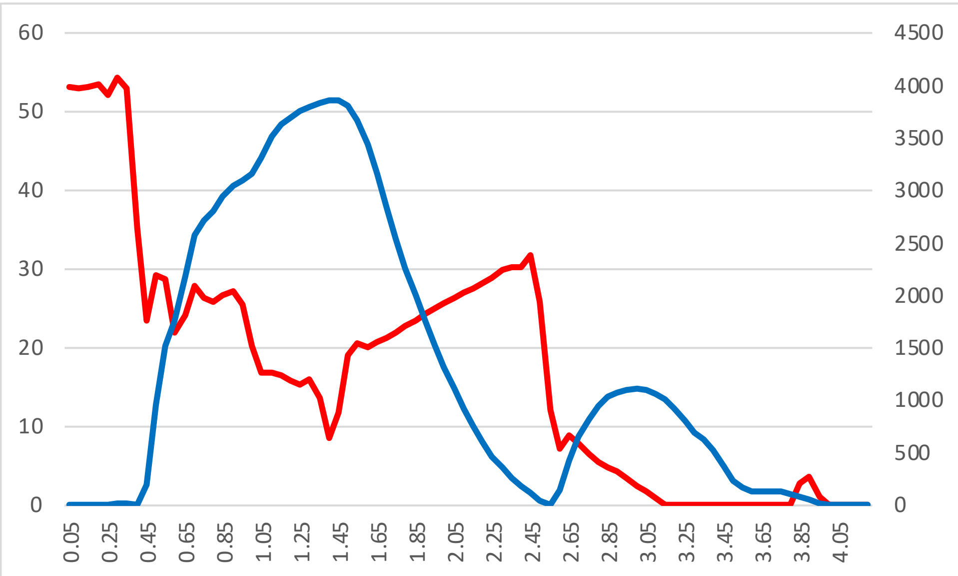
Event Joules = 97.05

Arc Flash Incident Energy = 0.00089 Cal/cm2. Category 0.

Arc Flash Boundary =12.4 mm

Time in Milli Seconds

Red = Volts Blue = Amps.



Test 2 Short Circuit. No BMS.

A second test was performed with the same setup as test 1. This showed a 3991 amps peak current before the 125-amp battery circuit breaker tripped.

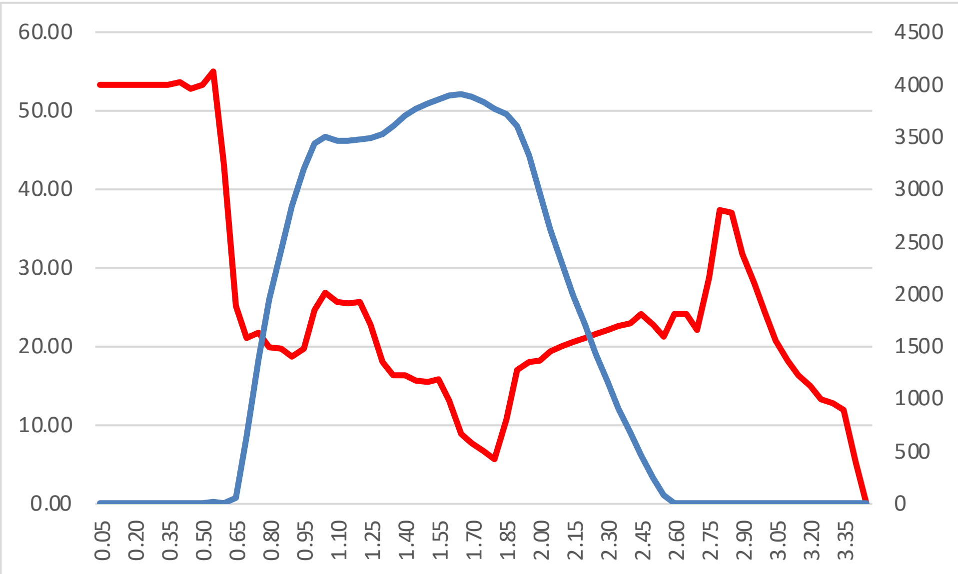
Event Joules = 89.8

Arc Flash Incident Energy = 0.00082 Cal/cm2. Category 0.

Arc Flash Boundary = 11.9 mm

Time in Milli Seconds

Red = Volts   Blue = Amps.



It's noted the duration of both short circuit events was very short. This is assumed to be because of the very low resistance and high amperage of the short circuit resulted in fast circuit breaker trip times.

Test 3 Short Circuit. No BMS.

Test 3 used the same setup as above but with an additional length of wire to increase the total circuit resistance added to the circuit. 16mm cable by 12m added to the circuit. Cable resistance calculated at 0.01335.

Existing resistance is 0.012273 plus 0.01335 ohms gives a total circuit resistance of 0.025623. This gives an estimated maximum fault current of 2.1KA.

Peak amps were recorded at 2075 amps.

Note the large increase of the event Joules for this test. Although peak current was lower, the total energy (Joules) was significantly higher than the previous short circuit tests due to the delayed circuit breaker trip time and longer event duration.

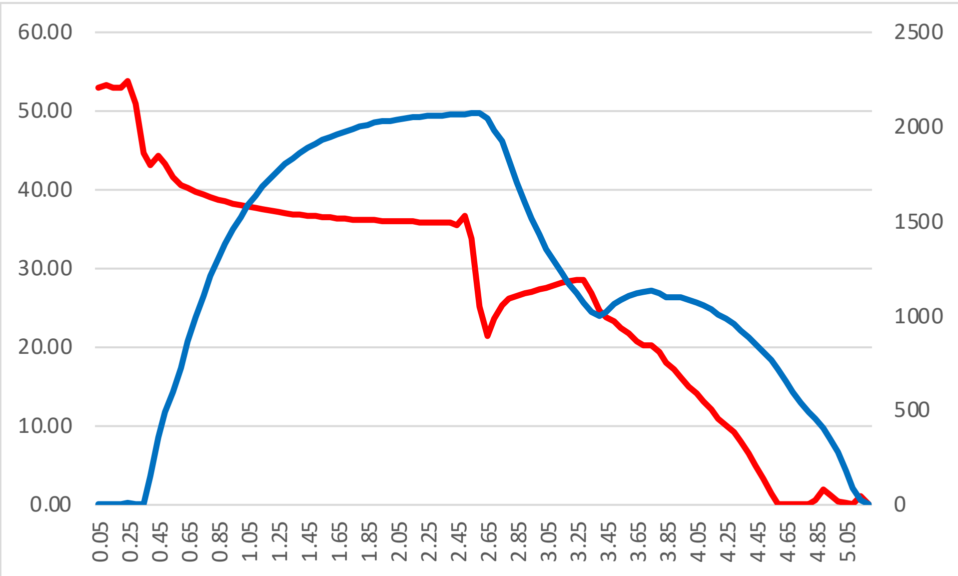
Event Joules = 183.9

Arc Flash Incident Energy = 0.00169 Cal/cm2. Category 0.

Arc Flash Boundary = 17.1 mm

Time in Milli Seconds

Red = Volts Blue = Amps.



Test 4 Short Circuit. No BMS.

e wire was added to the circuit to increase resistance. 100m of 6mm stranded (flex) tinned copper with a manufacturers spec of 3.3 milli ohm per meter for an additional cable resistance of 0.33 ohms.

Existing resistance is 0.012273 plus 0.33 ohms gives a total circuit resistance of 0.342273. This gives an estimated fault current of around 160 amps.

This test was performed with the cable still on the roll. A maximum current of 170.2 amps was measured.

It is noted the 125-amp circuit breaker did not trip during this test and it took 56.55 milli seconds to reach full current of 170.2 amps. The delay in reaching full current was assumed to be due to the magnetic field around the roll of cable.

The test was stopped when the cable become warm to touch after approximately 10 seconds.

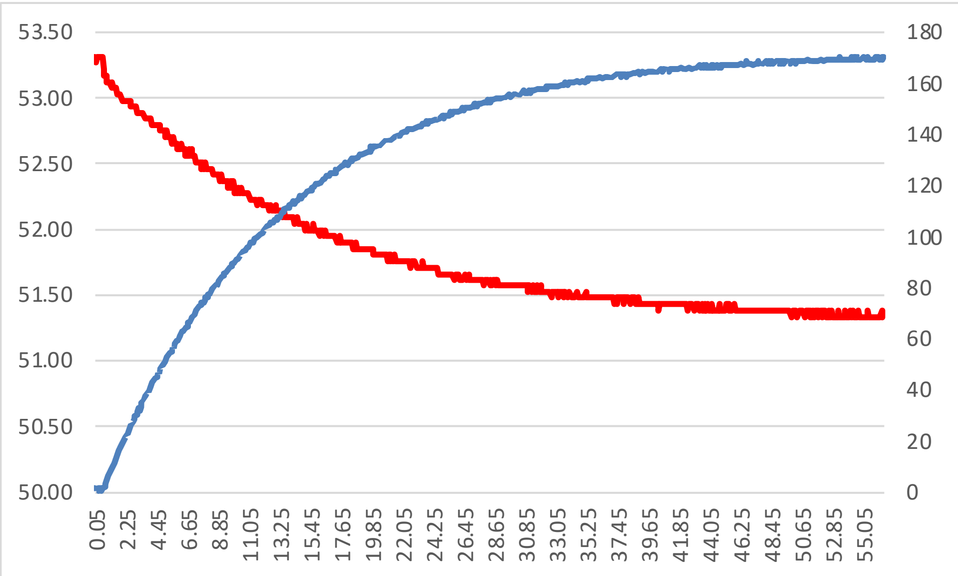
Event Joules = N/A. CB did not trip.

Blue = Amps.

Time in Milli Seconds

Red = Volts

Blue = Amps.



Test 5 Short Circuit. No BMS.

Test 5 is identical to test 4, but with the cable unrolled and laying on cool concrete.

Existing resistance is 0.012273 plus 0.33 ohms gives a total circuit resistance of 0.342273. This gives an estimated fault current of around 160 amps.

A maximum current of 170.9 amps was measured.

It is noted the 125-amp circuit breaker did not trip during this test. The test was stopped by turning the supply off the battery supply manually after the cable had become hot enough for the resistance to increase sufficiently to bring the load current below 125 amps. At this point the circuit breaker will not trip (ever) but the cable will keep increasing its temperature beyond its maximum temperature and become a fire risk.

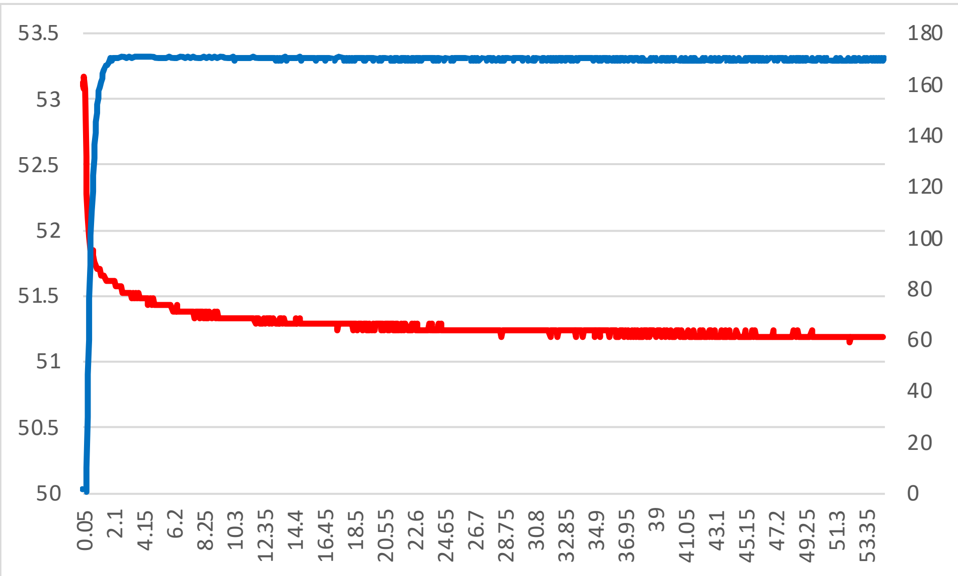
It took 2.55 milli seconds to reach full current. Note the speed to reach full current compared to Test 4. This is due to the magnetic field restricting current flow on test 4 as the cable was on a roll.

It took a total of 20 seconds for the current to fall below 125 amps. The test was stopped at this point.

Event Joules = N/A. CB did not trip.

Time in Milli Seconds showing inrush event. Same time scale as Test 4 Short Circuit.

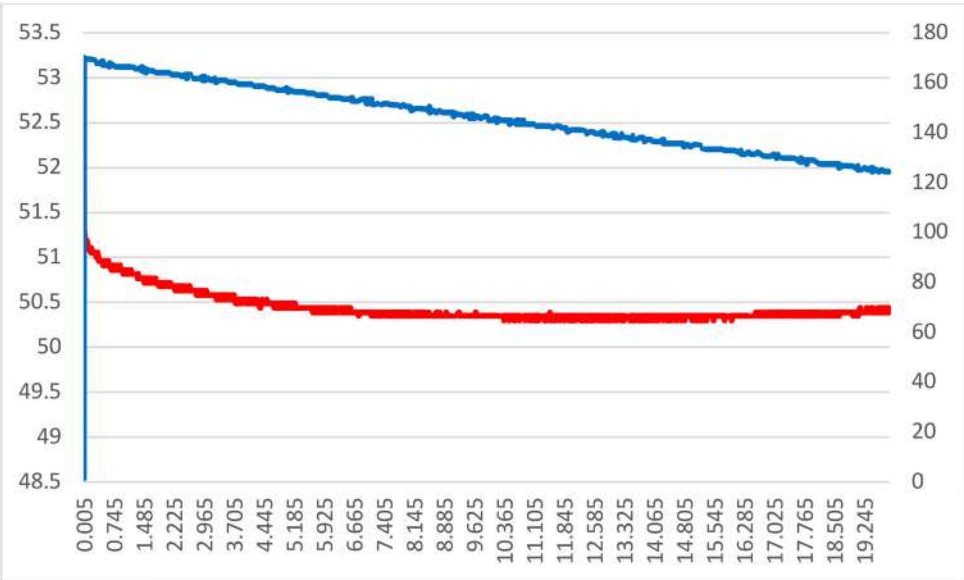
Red = Volts Blue = Amps.



Test 5 Short Circuit. No BMS. (continued)

Time in Seconds showing the temperature rise / resistance rise and corresponding current drop.
The graph below shows the full event until the current drops to 125 amps after just under 20 seconds.

Red = Volts Blue = Amps.



Test 6 Short Circuit. No BMS.

Some wire was added to the circuit to increase resistance. 20m of 4mm copper building wire on a roll with a manufacturers spec of 0.004275 ohm per meter for an additional cable resistance of 0.0855 ohms.

Existing resistance is 0.012273 plus 0.0855 ohms gives a total circuit resistance of 0.097773. This gives an estimated fault current of around 540 amps.

A maximum current of 524 amps was measured.

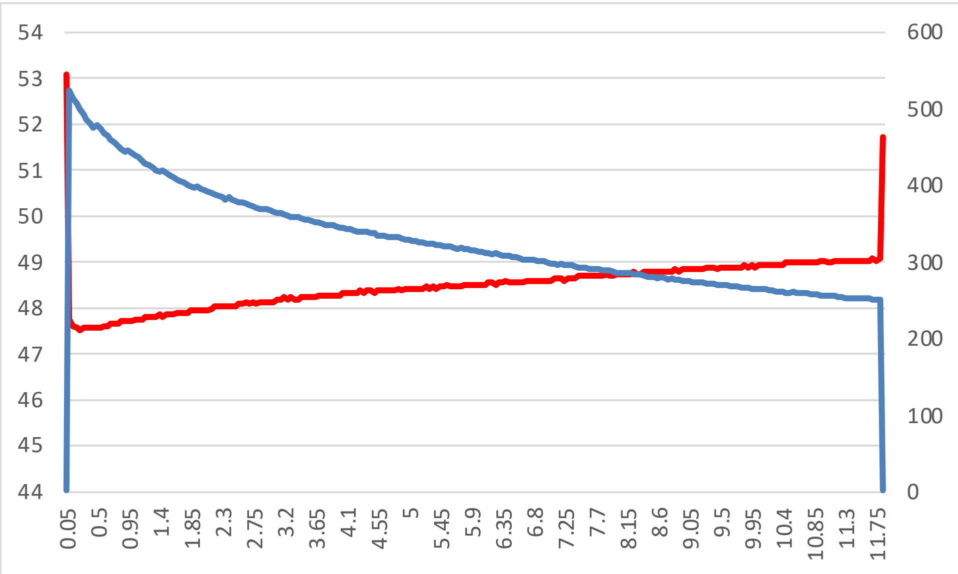
It is noted the 125-amp circuit breaker did not trip during this test. The test was stopped when the wire reached a critical temperature. This took about 12 seconds. At the end of the 12 seconds the current was down to 250 amps. It is noted the 4mm cable was severely damaged to a point of total insulation failure and exposed copper.

Event Joules = N/A. CB did not trip. Test was manually stopped.

Time in Seconds

Red = Volts

Blue = Amps.

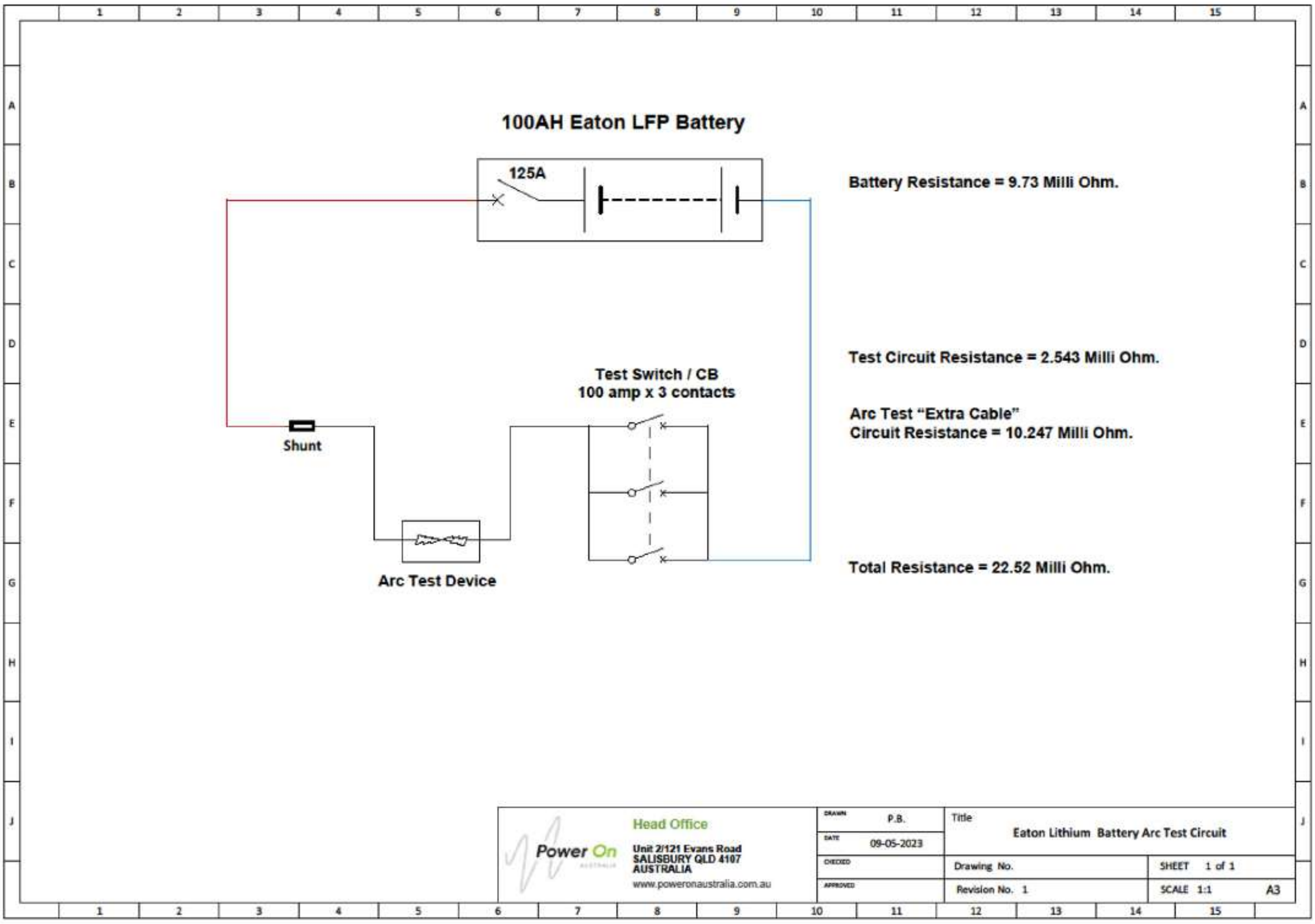


Arc Flash Testing.

As part of our testing, the same battery with the BMS disconnected (allowing full fault current via 125a CB) was connected to an Arc Gap Testing device. The aim of this test is to measure the current flow, circuit breaker reactions and maximum arcing distances a 54v DC supply can reach. All testing was done in the horizontal plane. Further investigation after the testing showed a potential for different results in a vertical plane. Future testing would be required to verify.

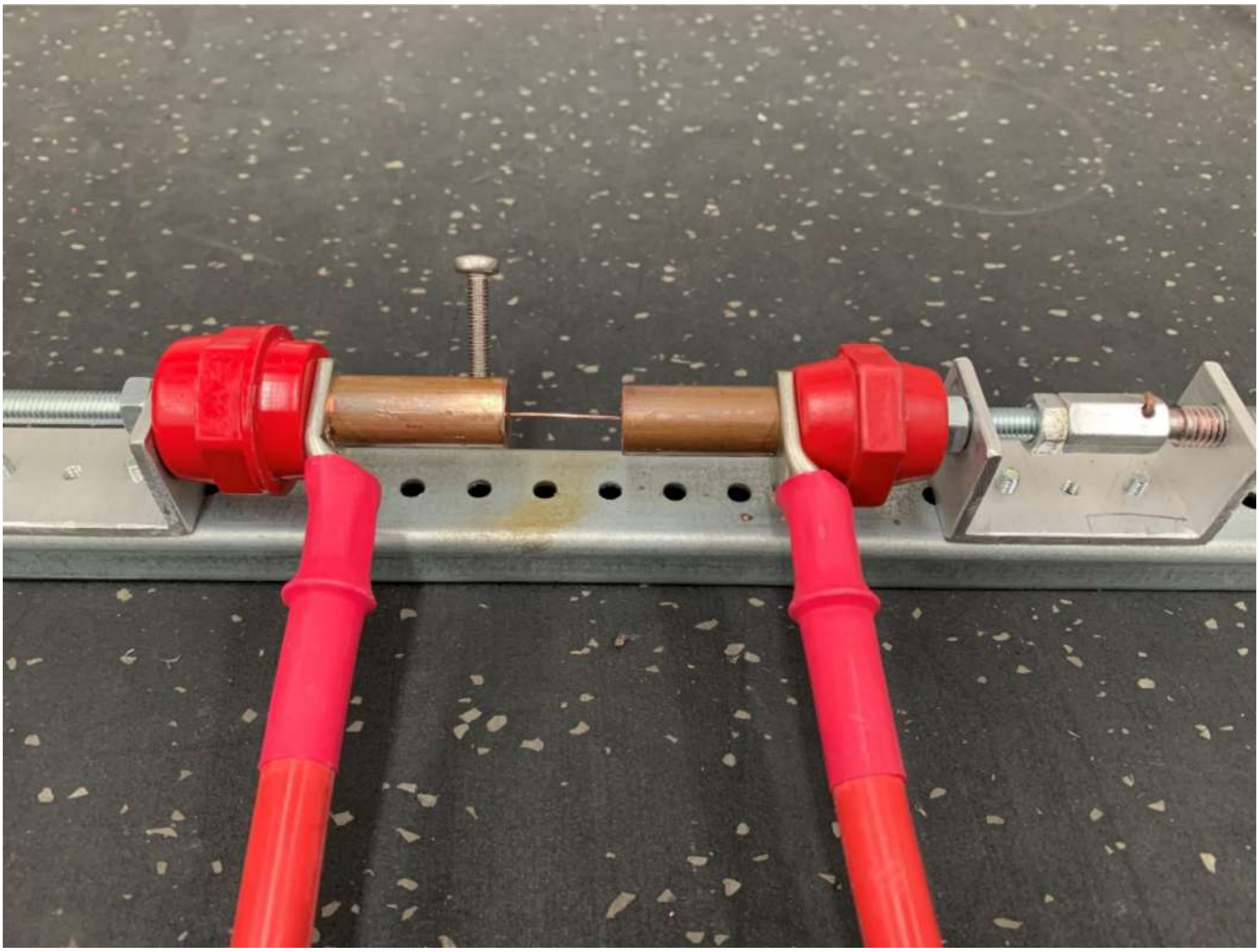
An arc gap tester was manufactured to allow the test wire to be finely adjusted via a 6mm screw to a "Just Closed" circuit on the test wire by using a multi meter prior to testing. This was wired to a total of 8m of 16mm cable (2 by 4m), 1m of 35mm (2 by 0.5m) with a 50-amp Anderson connector to allow for easy removal. The extra cable allowed for the arc test to be distanced from the switch and persons conducting the test. The extra resistance was measured at 10.247 Milli Ohms. This reduced the maximum possible fault current down to 2.4KA.

Arc Test wiring.



48 Volt Lithium Battery - fault current test report

Note: The 125-amp battery circuit breaker DID NOT TRIP with any of the Arc Tests below. In Arc Test 1 to Arc Test 6, the short circuit was broken by vaporising a gap between the +ve and -ve connections.



Arc test device showing a test wire ready to test.

Arc Test 1. No BMS.

A 1mm2 solid copper wire was filed to a fine point to reduce the copper in the arc for the first test.

The wire was fitted to the Arc Test device and set to just touching. When the power was turned on, this formed a direct short across the +ve and -ve via the fine tip on the 1mm wire.

When energised, the wire burnt away a total of 7.5mm with a peak current of 674 amps. In this situation the arc cannot be supported beyond 7.5mm. (Measured with vernier callipers)

Event Joules = 196.0

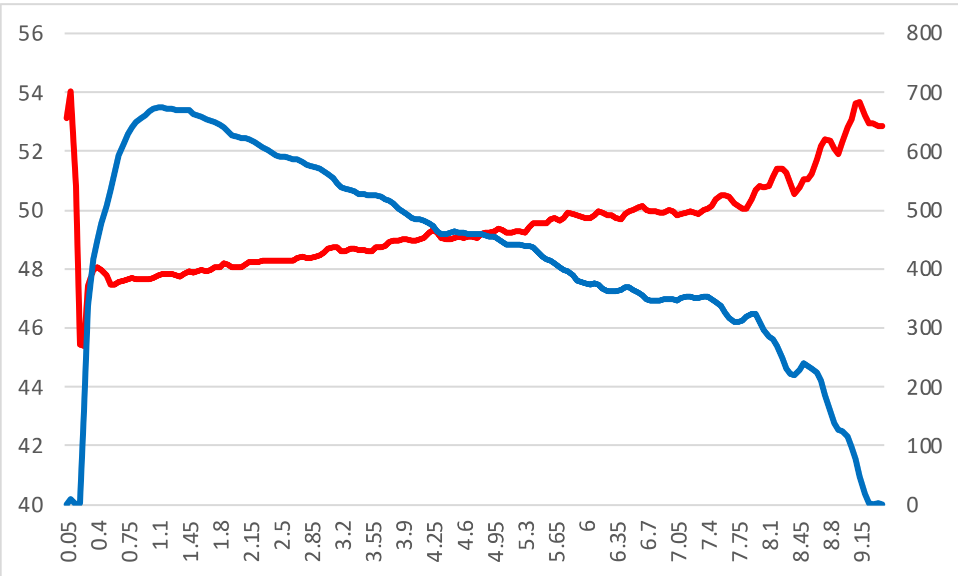
Arc Flash Incident Energy = 0.0018 Cal/cm2. Category 0.

Arc Flash Boundary = 17.6 mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



Arc Test 2. No BMS.

A 1mm2 solid copper wire was square cut and fitted to the arc device.

When energised, the wire burnt away a total of 7.5mm with a peak current of 1476 amps. In this situation the arc cannot be supported beyond 7.5mm.

Event Joules = 469.6

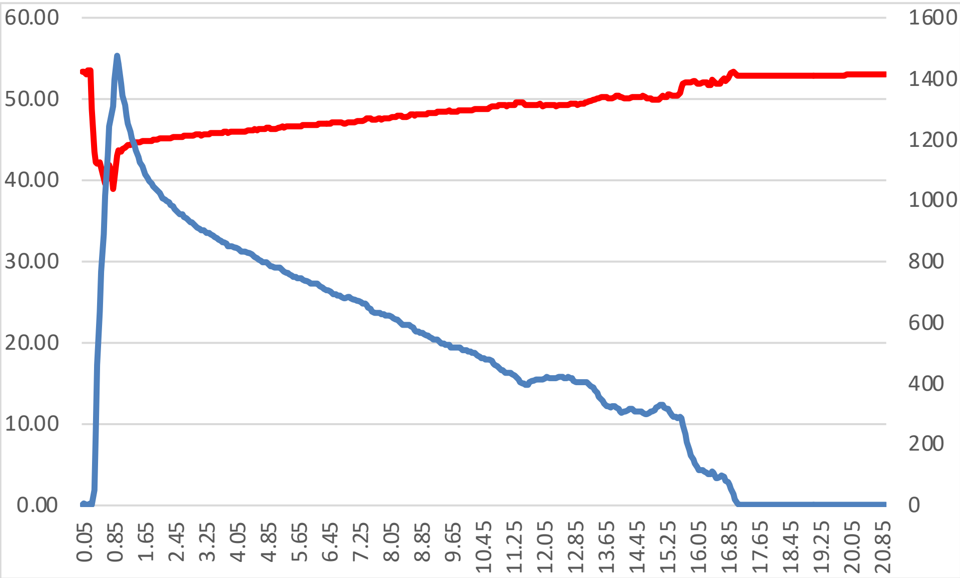
Arc Flash Incident Energy = 0.00431 Cal/cm2. Category 0.

Arc Flash Boundary = 27.3 mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



Arc Test 3. No BMS.

A 1mm2 solid copper wire was square cut and fitted to the arc device. Although I didn't measure the length of wire used, this length of 1mm wire was estimated to be 10mm longer than the above lengths.

When energised, the wire burnt away a total of 7.5mm with a peak current of 872 amps. In this situation the arc cannot be supported beyond 7.5mm.

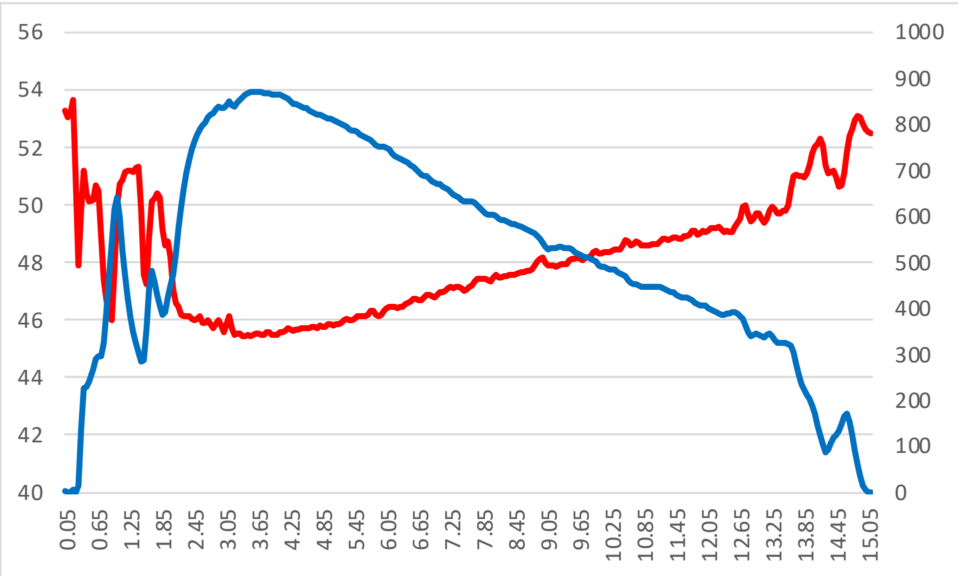
Event Joules = 378.0

Arc Flash Incident Energy = 0.00347 Cal/cm2. Category 0.

Arc Flash Boundary = 24.5 mm

Time in Milli Seconds

Red = Volts   Blue = Amps.



Arc Test 4. No BMS.

A 0.126mm2 solid copper wire was square cut and fitted to the arc device.

When energised, the wire burnt away a total of 7.5mm with a peak current of 711 amps. In this situation the arc cannot be supported beyond 7.5mm. (Measured with vernier callipers)

Event Joules = 145.8

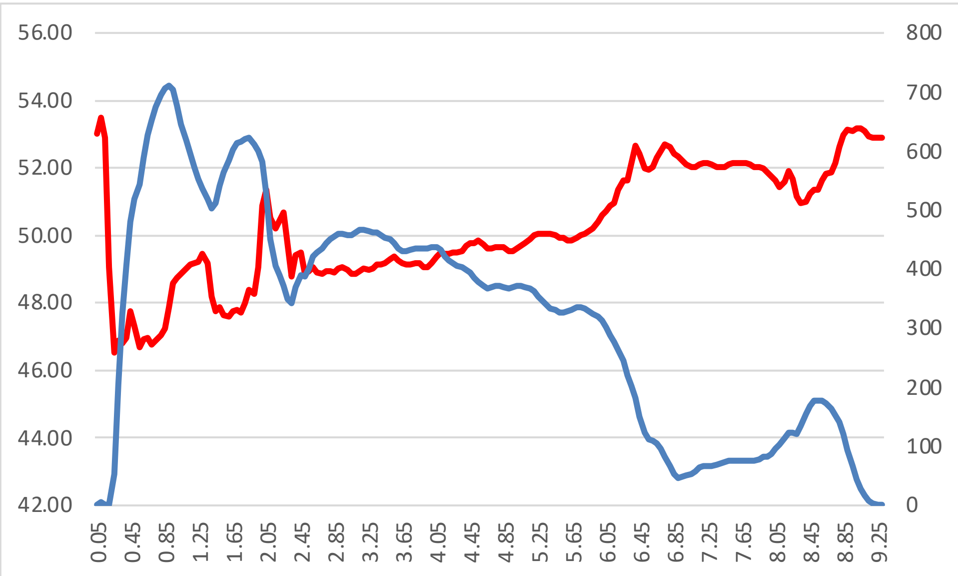
Arc Flash Incident Energy = 0.00134 Cal/cm2. Category 0.

Arc Flash Boundary = 15.2 mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



Arc Test 5. No BMS.

A 0.126mm2 solid copper wire was square cut and fitted to the arc device.

When energised, the wire burnt away a total of 7.5mm with a peak current of 467 amps. In this situation the arc cannot be supported beyond 7.5mm. (Measured with vernier callipers)

Event Joules = 102.7

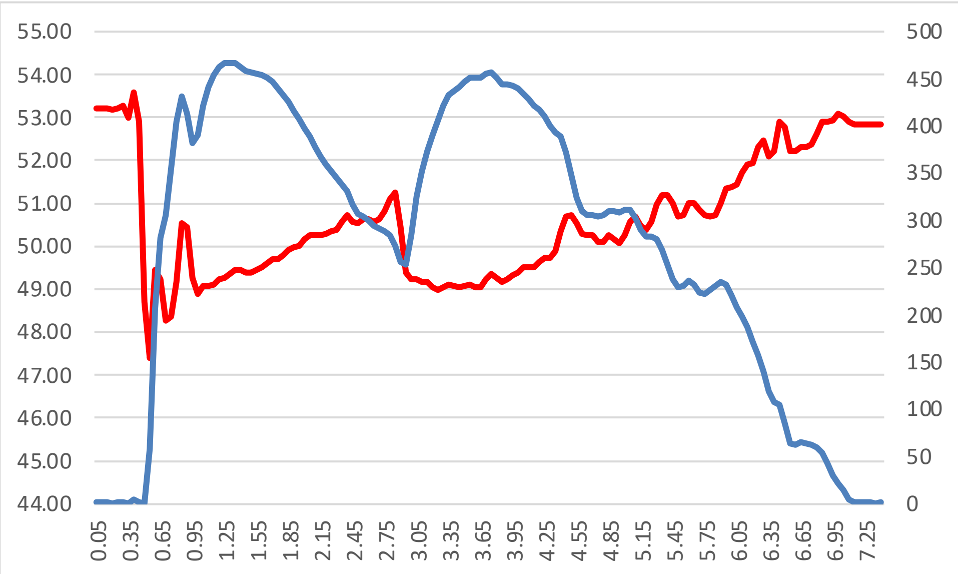
Arc Flash Incident Energy = 0.00094 Cal/cm2. Category 0.

Arc Flash Boundary = 12.8 mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



Arc Test 6. No BMS.

A solid copper 10mm diameter rod was machined down to a fine point at a 10-degree angle and fitted to the Arc Test Device. This rod was assumed to be able to support a significantly larger fault current due to the larger cross-sectional area of the copper. The tapered shape will also support a longer arc with the thin tip starting the arc at a small cross-sectional area with low (Relative to the copper area and gap) current flow. As the metal burns away, the arc will be supported by a larger cross-sectional area of copper remaining.

When energised, the rod burnt away a total of 5.6mm with a peak current of 930 amps. Although the gap was 5.6mm, it appears the arc did reach approximately 7.5mm along the rod. The end of the rod was rounded with definite metal vaporisation out to approximately 7.5mm. Another point to note is the extended duration and higher energy Joules of this event compared to the previous Arc Flash events. The assumption here is more copper to burn away takes a longer time and more energy. This Arc Event released the highest energy.

Event Joules = 739.6

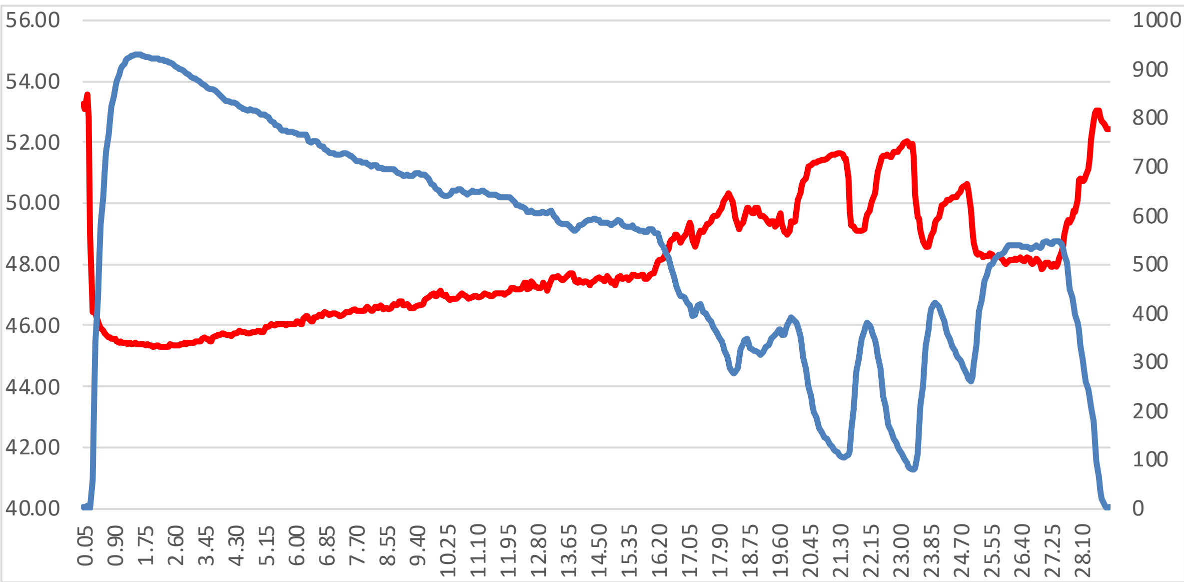
Arc Flash Incident Energy = 0.0068 Cal/cm2. Category 0.

Arc Flash Boundary = 34.2 mm

Time in Milli Seconds

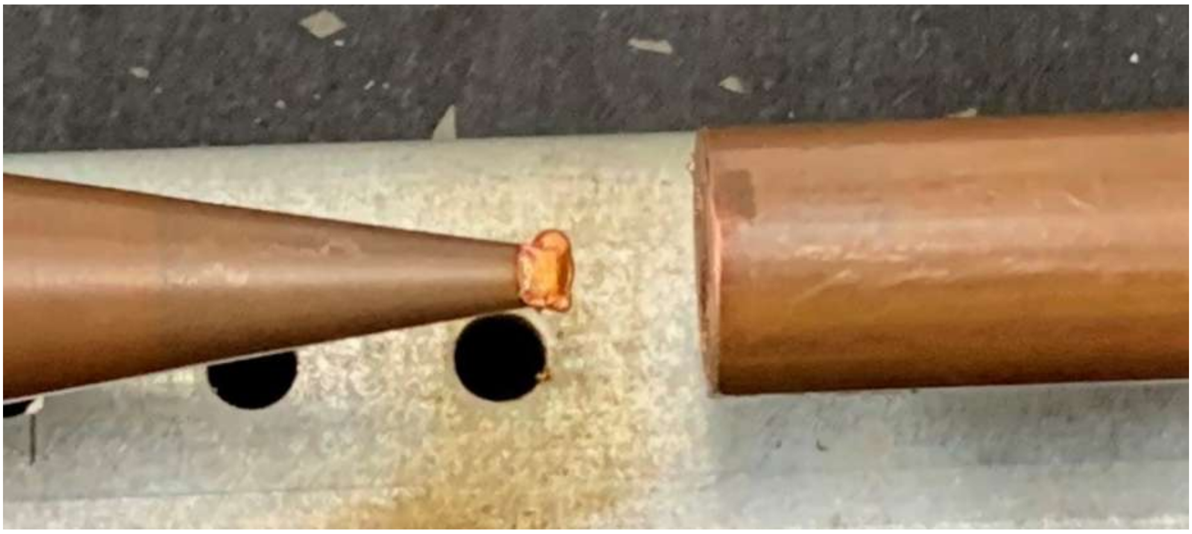
Red = Volts

Blue = Amps.



Arc Test 6. No BMS. (Continued)

Arc Test Device with copper rod after testing.



Arc Test Device showing the remains of the rod after Arc Test 6.
Note the gap is 5.6mm but the burn marks are out to 7.5mm.

Arc Test 7. BMS Connected.

The BMS was reconnected to allow normal battery control of the output.

A 0.126mm2 solid copper wire was square cut and fitted to the arc device.

When energised, the wire did not burn away. There was no spark, and no signs of heat. The battery BMS cut power to the output before any damage could be done. Maximum current recorded was 426 amps.

4 attempts of this test produced only one occurrence of a very small spark. This one occurrence of a spark showed little damage. The BMS shut down the power before any more than barely noticeable damage was done. The other 3 tests showed no visible signs apart from the battery going into short circuit protection.

Event Joules = Less than 1.

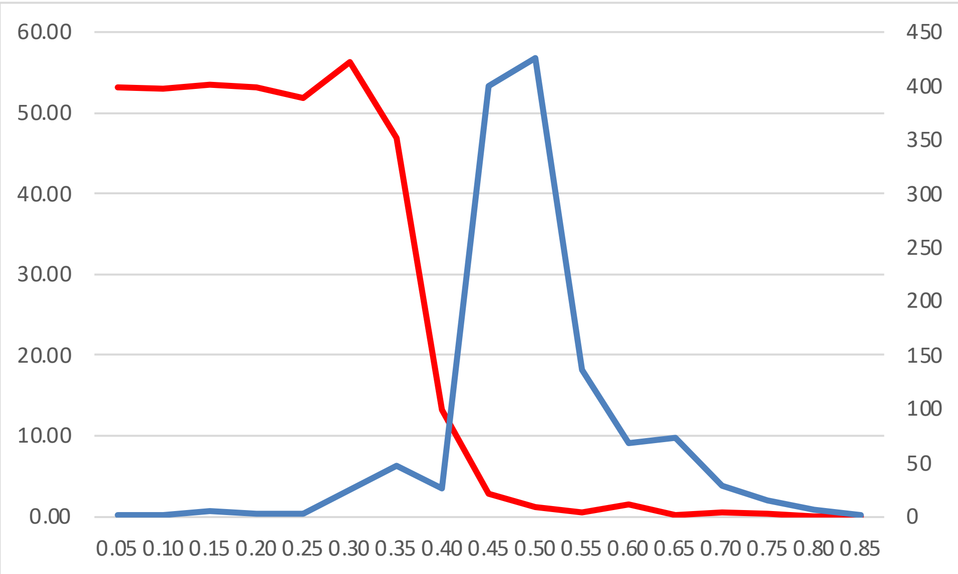
Arc Flash Incident Energy = 0.00001 Cal/cm2. Category 0.

Arc Flash Boundary = 1.3mm

Time in Milli Seconds

Red = Volts

Blue = Amps.



Arc Test 8. BMS Connected.

This test was performed as a more practical test to show the results of what could be seen as a likely accident.

A 0.126mm2 solid copper wire was square cut and fitted to the arc device. The gap was left open by a few millimetres.

Previous arc tests were performed by setting up a closed arc test prior to energising to allow for a safe working distance from the test. This test was performed much closer and with full PPE.

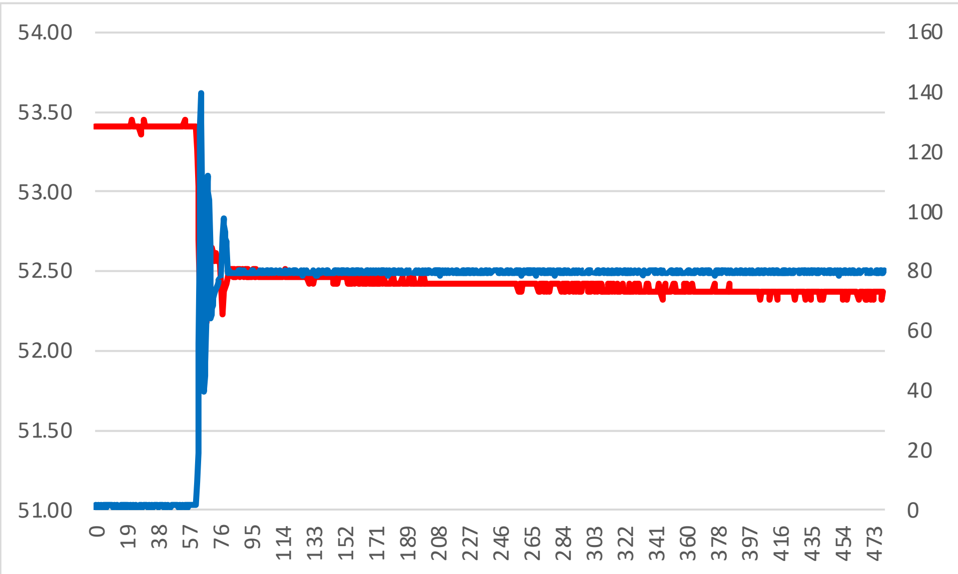
With the BMS fully functional and a live (53vDC) system, the small piece of wire was manually wound closed using the Arc Gap tester. As the gap closed, contact was made then the arc started. The arc continued as the wire was wound into the arc, but not with the severity of previous tests. After about 1/2 second the test was stopped. The assumption with this test is after the initial contact, the arc between the 2 pieces of copper maintained a constant distance. In essence I was arc welding with over 4KW of energy. A gap could not be measured due to movement of the test equipment after the power was disconnected via the switch.

Event Joules = N/A the test was manually stopped.

Time in Milli Seconds

Red = Volts

Blue = Amps.



Note the continuous nature of the current after the initial contact / arc is made.

Conclusions: Eaton supplied Lithium Battery using built in BMS.

- Internal resistance stated by the manufacturer (9.73 milli ohm) appears to be correct based on our calculations and testing results.
- The actual fault current in a short circuit event is significantly less than the calculated fault current in a battery with a working BMS. Our testing showed the BMS keeping the short circuit fault current below 500 amps.
- Under BMS control, the fault current duration during a short circuit event was very fast and less than 1 milli second. This is because of the fast action of the BMS.
- Under BMS control, the incident energy of a short circuit event is very small.
- Although the BMS has outstanding short circuit protection, from an overall system design point of view, we need to allow for the possibility of BMS failure. Designs should use the 9.73 milli ohm battery resistance as the basis of maximum current flow.
- Loads with excessively high inrush current may cause issues with the BMS. It is possible for a high inrush current to exceed the shutdown current value. Inrush current should not exceed the maximum discharge current specified by the manufacturer of 100 amps. Due to the possibility of slight resistance differences between batteries and cabling in a parallel battery bank, caution should be used in assuming doubling the batteries will give double the maximum current.
- A charging inrush event is also a factor to be considered in system design. This charge inrush event is covered in another technical note.
- A question remains as to the effects of a short circuit of multiple paralleled battery packs. This condition may involve multiple circuit breakers and lengths of cable from the batteries to the location of the fault. This extra circuit resistance could reduce the instantaneous peak current across each of the batteries resulting in the batteries not identifying the short. If standard electrical design principles are used in correctly sizing the cables and circuit breakers, this should not be an issue.

Conclusions: 48v supplies without BMS control. (BMS failure, lead acid or other Technology)

- Commonly used calculation methods for fault currents appear to be accurate when compared to our test results for short circuit events.
- Increasing the circuit resistance can increase the amount of energy being released in a short circuit event. This is opposite to some expectations. Although the instant, peak energy is reduced with a higher resistance, the duration of the event is extended due to the circuit breaker being slower to react, or not reacting at all.
- Although the size of the arcing conductor in an Arc event affected the peak current, the amount was less than expected with a change in conductor size. A relatively large conductor in Test 6 had a peak current of 930 amps, Test 4 showed a 0.126mm2 conductor had a peak current of 711 amps. The largest event was using a short length of 1mm2 copper as the conductor in Test 2 at 1476 amps.
- Arc events are difficult to control and release significantly more energy than a short circuit event. During multiple "staged" arc flash events both recorded and unrecorded, the 125-amp supply circuit breaker did not trip. The event was stopped by the gap of the arc burning out to approximately 7.5mm. Circuit Breakers appear to have a poor ability to disconnect arc flash events.
- With open air horizontal busbar spacing over 25mm, (approximately 3 times the 7.5mm measured arc gap) it would be unlikely an arc event caused by accidental shorting would be sustained between the busbars after the cause of the short is taken out of the equation by removing or vaporising.
- Vertical busbar spacing will require further testing.

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